	US ATLAS **HL-LHC Upgrade** **BASIS of ESTIMATE (BoE)**	**Date of Est:** **24-Nov-2015** **Prepared by:** **Mark Oreglia (UChicago)** **Docdb #:**

WBS number: 6.5.1.1	**WBS Title: Tile Calorimeter Main Boards**

WBS Dictionary Definition:

This WBS covers the fabrication of main boards (MB) which manage the data flow, power distribution, monitoring, and calibrations of the Tile Calorimeter front-end electronics. This MB is more radiation-tolerant than the current ones, which is a requirement for HL-LHC running.

The deliverable for WBS 6.5.1.1 is production of 1,100 boards. Additional tasks are parts procurement and monitoring of outsourced assembly, elevated temperature burn-in of cards with testing and repair, and assembly on the "drawer" mechanical structure for acceptance testing at CERN.

Estimate Type (check all that apply – see BOE Report for estimate type by activity):

___ Work Complete
___ Existing Purchase Order
___ Catalog Listing or Industrial Construction Database
_x__ Documented Vendor Estimate based on Drawings/ Sketches/ Specifications
_x__ Engineering Estimate based on Similar Items or Procedures
___ Engineering Estimate based on Analysis
_x__ Expert Opinion

Supporting Documents (including but not limited to):
Attachments: 1) Bill of Materials 2) Vendor PCB Assembly quote 3) Shipping quote

Details of the Base Estimate (explanation of the Work)

This BOE covers the production of 100% of the MB boards needed for the detector. The effort includes purchasing components and PCBs for the 1100 units needed, and shipping of the boards to CERN and acceptance testing.

Labor

The Main Board is a complex 16-layer PCB with a large number of ball-grid mounted integrated circuits. Experience acquired during production of prototype boards for a "demonstrator module" proved that the assembly process by outsourced firms needs to be monitored by an experienced Electrical Engineer (EE) who can aid in debugging faults in the process early on. It is also important for a trained Electronics Technician (ET) to perform an initial test on bare PCBs and again as they arrive from the assembly house to detect and repair faults. The assembled boards are received from the vendor at the University of Chicago, where they are mounted in burn-in fixtures and monitored in real time during temperature cycling over a 5 day period which mimics 15 years of field operation. This process requires that the front-end cards (FEB, manufactured by a different group) be connected to the MB during the burn-in. Experience from the production of the current motherboards, and especially recent production of MB prototypes, suggests that approximately 5-10% of the boards will need rework due to faulty components or soldering.

Depending on the severity of the problem, the diagnosis and repair will be done by the EE or ET. Undergraduate students (UG) will be employed to mount boards in the burn-in fixtures, monitor them periodically, and dismount and store units that pass. Experience from the production of 1100 main boards for the current ATLAS detector showed that the burn-in and repair process required almost full FTE labor by the ET and approximately 25% FTE oversight by the EE. Shipping the boards in batches to CERN will incur materials- and ET labor costs, and significant time by the EE is required at CERN to attend two expert weeks per year and train staff to do acceptance tests.

Labor costs for the EE and ET working in the Electronics Development Group (EDG) incur no overhead.
Labor FTEs are based on experience with the recent prototypes produced for the demonstrator and our experience in producing the motherboards for the current ATLAS Tile calorimeter. The breakdown is as follows (with "Y1" indicating first year of full production, taken to be 2020):

- Parts packages, short-test PCBs: 10% FTE ET in Y1,Y2
- Oversee PCB assembly, initial testing, debugging with assy hse: 10% FTE EE,ET in Y1,Y2
- Mount in burn-in fixtures; supervise students: 10% EE, 60% ET, 1 FTE UG in Y1, Y2
- Diagnose and repair failures: 10% EE and ET in Y1, Y2
- Inventory, crate and ship to CERN: 5% ET in Y1, Y2, Y3
- Acceptance test training at CERN and system integration meetings: 10% EE per year

Summary FTE's: 2.8 EE, 2.95 ET, 2 Undergraduate Students

Materials

Cost of components and PCBs is taken from the Bill of Materials (BoM) for the recent production of prototype MB cards used in the "demonstrator" – a prototype Tile Calorimeter module currently undergoing testing at CERN; the BoM is shown in Attachment 1. This BoM was for production quantity of only 8 cards and shows retail prices by Digikey. Our EE expert is confident (based on mutch experience with Arrow as a supplier) that a full production lot of the more expensive IC's accounting for 87% of the cost will realize a 20% or higher discount over the attached BoM. We have a quote from the assembly firm for PCB assembly in large quantity (Attachment 2). To get the best batch pricing, all passive components will be purchased in one lot; purchase of more expensive items such as PCBs, ADCs, FPGAs and DC-DC converters will be done in two batches. Shipping costs were estimated based on a quote from UPS based on the size and weight of the required crating.

Travel

Travel to CERN by the EE is needed during the production phase to attend expert weeks and to train staff to do the acceptance tests. We have estimated that two week-long trips per year will be necessary, based on our experience in constructing the demonstrator as well as the motherboard production during 2000-2003; the average cost of a week at CERN is estimated to be $2570. Also included for the PCB assembly process are 6 commuter trips to Schaumberg, IL, so the EE can debug the process with the assembly house engineers; this is a local trip incurring only mileage reimbursement of $100 per trip. There is no overhead on travel by EDG staff.

A cost summary is tabulated below.

WBS	Deliverable	Task	Labor Hrs	Labor $	M&S $	Travel $	Total $
6.5.1.1	**Main Boards**		**9,146**	**633,198**	**1,109,613**	**31,240**	**1,774,051**
	Production procurement	MB1120	355	27,982	883,850	0	911,832
	Engineering labor		355				
	Student labor		0				
	Production PCB assembly	MB1130	710	73,183	200,200	400	273,783
	Engineering labor		710				
	Student labor		0				
	Production Burn-in	MB1160	6,394	344,391	0	0	344,391
	Engineering labor		2,842				
	Student labor		3,552				
	Production diagnose&repair	MB1170	710	73,183	0	0	73,183
	Engineering labor		710				
	Student labor		0				
	Ship to CERN	MB1210	266	21,303	25,563	0	46,866
	Engineering labor		266				
	Student labor		0				
	Acceptance test	MB1220	710	93,156	0	30,840	123,996
	Engineering labor		710				
	Student labor		0				

Schedule:

ATLAS management has scheduled installation of the Tile Calorimeter modules to begin early in 2024; possibly even late 2023. Consequently, the complete number of 256 tested and assembled drawers must be ready by 2023Q4. To meet this target with available manpower and resources, 18 months of production are necessary over two years; this also provides for a comfortable 6 month schedule float. These requirements call for the following timeline:

- 2018-19: final design and prototype pre-production
- 2020: parts procurement, production and testing of 550 boards
- 2021: parts procurement, production and testing of 550 boards
- 2021-23: acceptance testing at CERN and mounting on drawer structures
- 2023: full system testing and start of installation

Assumptions:

- Chicago "3in1" version of FEB adopted. MB components differ for other versions.
- Preproduction funded by operations or other pre-construction sources
- 20% quantity discount on ICs
- Timely receipt of FEBs from Clermont-Ferrand
- Component failure rate < 10%
- MB rework rate < 15%

Risk Analysis

We note that the recent production of a demonstrator prototype employing these MBs leads to high confidence in performance, cost and schedule. The MB production is essentially self-contained, so there is really no external dependency apart from receiving at least one batch of FEB from Clermont-Ferrand.

Schedule Risk:

Probability: Low
Potential Problem: higher PCB failure rate.
Mitigation: 33% schedule float should be sufficient to address any plausible failure rate.

Schedule Risk:

Probability: Low
Potential Problem: late delivery of FEB from Clermont-Ferrand.
Mitigation: In the event of late FEB delivery, MB production can proceed with only one batch of FEB; these FEB could even be reclaimed from demonstrator modules.

Cost Risk:

Probability: Low
Potential Problem: higher EDG labor rates.
Mitigation: none.
Labor rates include 3% inflation; the average over 10 years at UChicago has been 2%.

Cost Risk:

Probability: Low
Potential Problem: higher failure rate necessitating more repair, or increased component costs.
Mitigation: More EE labor to augment repair force; component costs should be well within 30% contingency. Recent experience with the demonstrator and purchase of components validates costing and debug time.

Cost Risk:

Probability: Low
Potential Problem: QIE or FATALIC version of FEB+MB chosen.
Mitigation: These versions of the MB are simpler and have no ADCs; parts cost would be lower.

Technical/Scope Risk:

Probability: Negligible
Potential Problem: Card component no longer radiation qualified.
Mitigation: Find alternative component.
The components are not exotic, with many alternatives. Radiation testing already virtually certifies the components chosen.

M&S Contingency Rules Applied

50%

We now estimate the contingency based on the rules for M&S. It depends on the maturity of the cost estimate.

5) 40-60% contingency on: items with a detailed conceptual level of design; items adapted from existing designs but with extensive modifications, and/or made more than 2 years previous with documented costs. A physicist or engineering estimate uses this level.

Labor Contingency Rules Applied

50%

We now estimate the contingency based on the rules for Labor.. It depends on the maturity of the cost estimate.

> 40-60% contingency for a task that is not yet completely defined, but is analogous to past activities; for example, a fabrication activity similar to, but not exactly like, items fabricated for other activities; for example, design labor for items similar to, but not exactly like, previous designs.

Comments:

There is high confidence in cost and risks based on the recent successful test of MB prototypes and radiation testing.

Attachments:

Attachment 1: Bill of Materials

B2842 Component Order List (B2842_order_shipment_062915.xlsx)							
	Fukun Tang						
	ftang@uchicago.edu						
	773-834-4286						
	6/29/2015	update 6/11/2015					
Part name	Part #	Digikey #	Geometry	Qty/BD	Unit Price	Qty Order	subtotal $
ICs							
16-bit ADC	MAX1169BEUD+	MAX1169BEUD+-ND	TSSOP14	12	$6.30	250	$75.60
Oct 12-bit DAC	LTC2656IUFD-L12#PBF	LTC2656IUFD-L12#PBF-ND	QFN20_4x5mm	8	$12.210	200	$97.68
40Mbps 12-bit ADC	LTC2264CUJ-12#PBF	LTC2264CUJ-12#PBF-ND	QFN40_6x6mm	12	$18.070	300	$216.84
Op Amplifier	LTC2051CS8#PBF	LTC2051CS8#PBF-ND	soic8	2	$2.150	150	$4.30
Dual 4A DC/DC	LTM4619EV#PBF	LTM4619EV#PBF-ND	uModule_144	4	$20.339	100	$81.36
Negative DC/DC Controller	LT3759EMSE#PBF	LT3759EMSE#PBF-ND	MSOP12_TPAD	2	$3.360	50	$6.72
Serial EPROM	EPCS4SI8N	544-1379-5-ND	soic8	4	$13.000	80	$52.00
FPGA	EP4CE10F17C7N	544-2668-ND	FBGA256_17x17mm	4	$33.670	80	$134.68
MOSFET	SI7848BDP-T1-GE3	SI7848BDP-T1-GE3CT-ND	soic8_ppak	2	$1.440	10	$2.88
40MHz Clock Generator	ECS-3525-400-B-TR	XC1057CT-ND	5mmx3.2mm	4	$3.107	50	$12.43
400-pin Aray Male Conn	45970-4715	WM4985CT-ND	400-pin Male Conn.	1	$19.899	25	$19.90
Passive Components:							
3A FUSE BLOK	01543.15DRL	01543.15DRL-ND	smf_fuse_blok	2	$1.165	50	$2.33
5-pin signal connector	berg_conn5		berg_conn5	12	$0.100	100	$1.20
10-pin JTAG Connector	M50-3500542	952-1383-ND	jtag_connst	2	$0.855	40	$1.71
40-pin ribbon connector	ca40nfhlr_ra		ca40nfhlr	12	$0.250	100	$3.00
4-pin power connector	0039301040	WM1352-ND	4-pin power conn	3	$0.780	60	$2.34
3-pinpower connector	0039303035	WM18446-ND	3-pin power conn	2	$0.890	50	$1.78
4-pos dip switch	218-4LPST	CT2184LPST	4-pos sm dip switch	2	$1.180	30	$2.36
Schottky 30V 5A Diode	RB085B-30TL	RB085B-30TLCT-ND	DPAK	4	$0.984	100	$3.94
RES 0.0 OHM 1/10W JUMP 0402 SMD	ERJ-2GE0R00X	P0.0JTR-ND	R0402	38	$0.002	10000	$0.09
RES 0.005 OHM 1W 1% 0805	KRL2012E-M-R005-F-T5	408-1595-1-ND	R0805	2	$0.392	100	$0.78
RES 22.0 OHM 1/10W 1% 0402 SMD	ERJ-2RKF22R0X	P22.0LTR-ND	R0402	20	$0.003	10000	$0.07
RES 51.0 OHM 1/10W 1% 0402 SMD	ERJ-2RKF51R0X	P51.0LTR-ND	R0402	48	$0.003	10000	$0.17
RES 56.0 OHM 1/16W 1% 0402 SMD	RC0402FR-0756RL	311-56.0LRTR-ND	R0402	12	$0.001	10000	$0.02
RES 100 OHM 1/10W 1% 0402 SMD	ERJ-2RKF1000X	P100LTR-ND	R0402	36	$0.003	10000	$0.12
RES 499 OHM 1/10W 1% 0402 SMD	ERJ-3EKF4990V	P499HTR-ND	R0402	24	$0.002	10000	$0.05
RES 1.00K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1001X	P1.00KLTR-ND	R0402	126	$0.003	10000	$0.44
RES 1.21K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1211X	P1.21KLTR-ND	R0402	4	$0.003	10000	$0.01
RES 1.50K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1501X	P1.50KLDKR-ND	R0402	2	$0.005	5000	$0.01
RES 2.00K OHM 1/10W 1% 0402 SMD	ERJ-2RKF2001X	P2.00KLTR-ND	R0402	4	$0.003	10000	$0.01
RES 3.83K OHM 1/10W 1% 0402 SMD	ERJ-2RKF3831X	P3.83KLTR-ND	R0402	6	$0.003	10000	$0.02
RES 4.99K OHM 1/10W 1% 0402 SMD	ERJ-2RKF4991X	P4.99KLTR-ND	R0402	4	$0.003	10000	$0.01
RES 9.10K OHM 1/10W 1% 0402 SMD	ERJ-2RKF9101X	P9.10KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 10.0K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1002X	P10.0KLTR-ND	R0402	98	$0.003	10000	$0.34
RES 11.5K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1152X	P11.5KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 15.8K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1582X	P15.8KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 27.4K OHM 1/10W 1% 0402 SMD	ERJ-2RKF2742X	P27.4KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 28.0K OHM 1/10W 1% 0402 SMD	ERJ-2RKF2802X	P28.0KLTR-ND	R0402	4	$0.003	10000	$0.01
RES 45.3K OHM 1/10W 1% 0402 SMD	ERJ-2RKF4532X	P45.3KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 48.7K OHM 1/10W 1% 0402 SMD	ERJ-2RKF4872X	P48.7KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 60.4K OHM 1/10W 1% 0402 SMD	ERJ-2RKF6042X	P60.4KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 84.5K OHM 1/10W 1% 0402 SMD	ERJ-2RKF8452X	P84.5KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 100K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1003X	P100KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 105K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1053X	P105KLTR-ND	R0402	2	$0.003	10000	$0.01

RES 121K OHM 1/10W 1% 0402 SMD	ERJ-2RKF1213X	P121KLTR-ND	R0402	2	$0.003	10000	$0.01
RES 25.5 OHM 1/10W 1% 0402 SMD	ERJ2RKF25R5X	P25.5LTR-ND	R0402	24	$0.003	10000	$0.07
CAP CER 12pF 50V 1% NP0 0402	GRM1555C1H120FA01D	490-6196-2-ND	C0402	12	$0.009	10000	$0.11
CAP CER 22PF 10V 5% NP0 0402	C0402C220J8GACTU	C0402C220J8GACTU-ND	c0402	8	$0.061	10000	$0.49
CAP CER 1000PF 50V 5% NP0 0402	C1005C0G1H102J050BA	445-6846-2-ND	c0402	56	$0.020	10000	$1.12
CAP CER 10000PF 25V 10% X5R 0402	C1005X5R1E103K050BA	445-7386-6-ND	c0402	26	$0.005	5000	$0.13
CAP CER 0.1UF 16V 10% X5R 0402	C1005X5R1C104K050BA	445-4970-2-ND	c0402	649	$0.005	10000	$3.00
CAP CER 1UF 6.3V 10% NP0 0402	C2012C0G1H103J060AA	04026W105KAT2A-ND	c0402	60	$0.126	10000	$7.56
CAP CER 2.2UF 10V 10% X5R 0402	C1005X5R1A225K050BC	445-7392-2-ND	c0402	46	$0.064	10000	$2.94
CAP CER 4.7UF 10V 20% X5R 0402	C1005X5R1A475M050BC	445-8023-2-ND	c0402	26	$0.008	10000	$0.21
CAP CER 4.7UF 25V 10% X5R 0805	C2012X5R1E475K125AB	445-4116-2-ND	C0805	6	$0.060	2000	$0.36
CAP CER 100UF 16V 20% X5R 1210	EMK325ABJ107MM-T	587-3152-2-ND	C1210	28	$0.765	1000	$21.42
FERRITE CHIP BEAD 600 OHM SMD	MPZ2012S601A	MPZ2012S601A	F0603	32	$0.027	4000	$0.88
INDUCTOR SHIELD DUAL 3.3UH SMD	DRQ127-3R3-R	513-1308-1-ND	DRQ127-3R3-R	2	$1.667	50	$3.33
10uF 6.3V 20% X5R 0402	CL05A106MQ5NUNC	1276-1451-1-ND	C0402	20	$0.119	100	$2.38
47uF 6.3V 20% X5R 0805	C0805C476M9PACTU	399-5506-1-ND	C0805	56	$0.333	100	$18.66
47uF 10V 20% X5R 1206	GRM31CR61A476ME15L	490-55528-2-ND	C1206	72	$0.176	100	$12.67
Crimp terminal	0457503112	WM10851-ND			$0.134	100	$0.00
4-pin power conmating socket	0039012040	WM3701-ND	Mating PN WM1352-ND		$0.216	100	$0.00
					Passive components:		$96.23
					ICs, less 20%		$363.51
	NB: PCB qty 100=$400			PCB:	PCB, qty 550		$240.00
	NB: Assy qty 100 = $190.20			Assy:	Assy, qty 550		$182.00
				cost/bd qty 550:			**$1,081.74**

Attachment 2: Vendor Quote: PCB assembly

BESTProto Inc.
Your product development partner

QUOTATION

Date	Quote Number:
11/5/2015	5211

BESTProto Inc.
3603 Edison Place
Rolling Meadows IL 60008
Ph: 224-387-3280 Fax: 224-387-3290
www.bestproto.net

University of Chicago
Physical Sciences Division
5747 S. Ellis Ave GHJ 303
Chicago, IL 60637

BESTProto, Inc. is pleased to quote the following price and delivery information:

Item	Qty	Customer P/N, Description	Piece Price	*Lead Time
1	100	PCB Assembly (Labor Portion), B2800	190.20	10 Days
2	100	PCB Assembly (Labor Portion), B2800	247.20	5 Days
3	550	PCB Assembly (Labor Portion), B2800	182.00	10 Days
4	1,100	PCB Assembly (Labor Portion), B2800	180.00	20 Days
		*Lead times are subject to available capacity at the time of order. Standard lead time is approximately 10 days after receipt of all required parts and files.		
		Sales Tax if Applicable (9.0%)		

Attachment 3: UPS shipping quote

For crate of 50 boards.

Calculate Time and Cost

Air Freight Time and Cost Summary

Based on the selected destination, 1 or more additional days time in transit may apply.

Air Freight Results

Air Freight Service	Total	Ship Date	Expected Delivery to Destination*
UPS Air Freight Direct^{SM} (Non-Guaranteed)	1,162.00 USD	Tuesday 11/03/2015	06:00 PM Monday 11/09/2015

Base Transportation:	90.00	USD
Declared/Insured Value Surcharge:	850.00	USD
Peak Season Surcharge:	0.00	USD
Electronic Export Information (EEI):	15.00	USD
Security Fee:	22.00	USD
Fuel Surcharge:	105.00	USD
Misc. Origin Fees:	80.00	USD
Total:	**1,162.00**	**USD**